Southeastern United States Summer Rainfall Framework and its Implication for Seasonal Forecast

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NOAA Climate Diagnostic and Prediction Workshop

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Motivations

- The Southeastern United States (SE US) is one of the fastest developing regions in the nation, thus the warm season precipitation becomes increasingly more important for this region.

- Reliable climate prediction for SE US relies on accurate statistical inference on summer rainfall.

2005 SE US Flood

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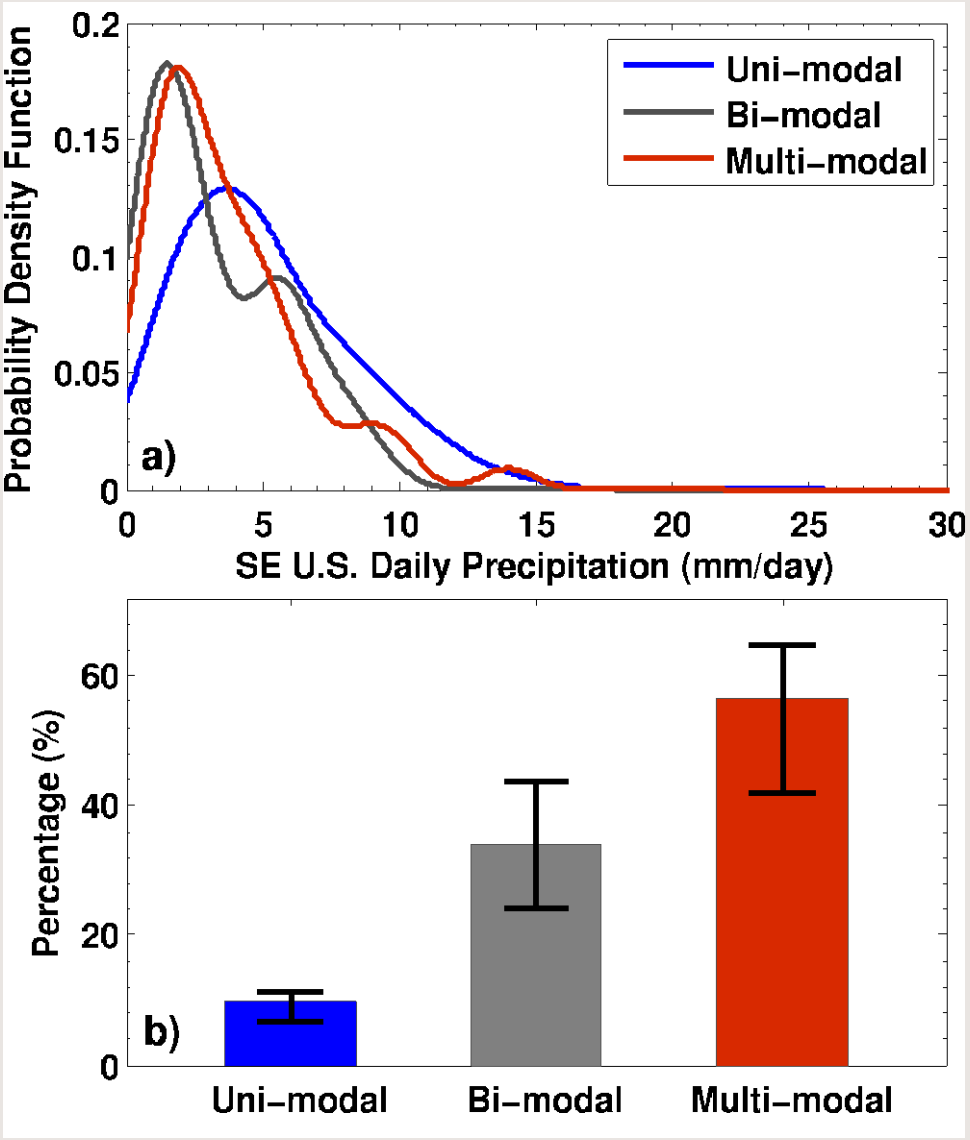
Motivations

- Previous rainfall statistical inference takes the approach of fitting probability distributions with predefined kernels (e.g. Gamma, Weibull).
- These traditional distribution fail to capture the “multi-modal” features of SE US summer rainfall; thus cannot provide reliable statistical inference.



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From Li and Li, 2013: Southeastern United States Summer Rainfall Framework and its Implication for Seasonal Prediction, *Environ. Res. Letts.* (In Press)

Goal of This Study

- Construct a new probability framework that can well represent the “multi-modal” features of SE US summer rainfall distribution
- Explore the possible linkages between climate factors and the complete spectrum of rainfall distribution
- Assess the potential predictability skill according to these linkages

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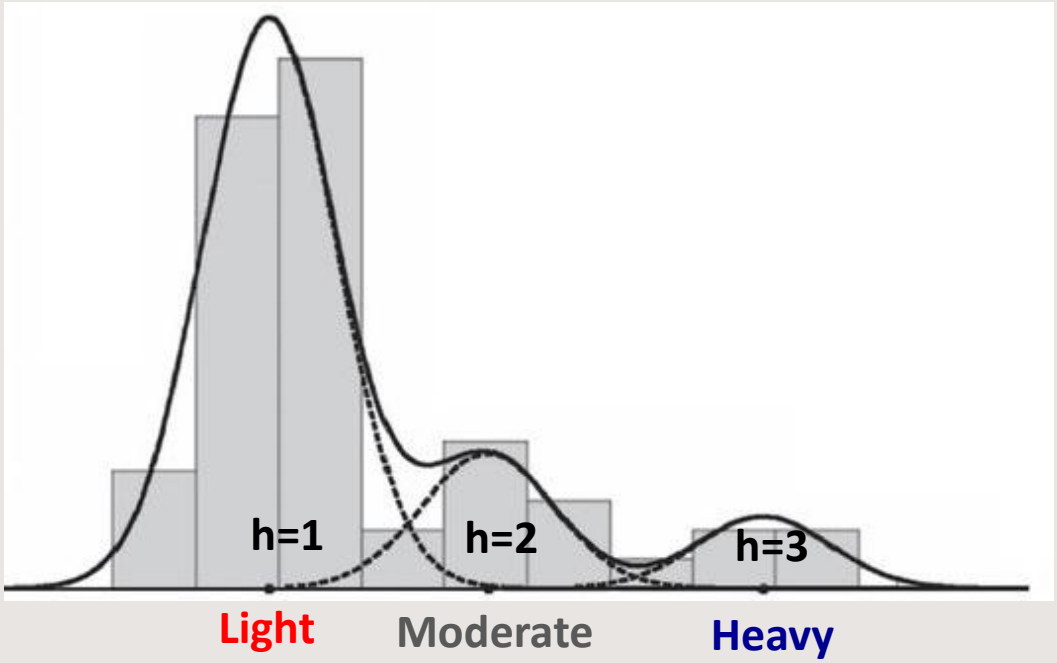
Configuration of Rainfall Framework

3-cluster *Normal* Mixture Models:

$$y_i|\pi,\mu,\phi \sim \sum_{h=1}^{3} \pi_h N\left(y_i|\mu_h,\phi_h\right)$$

3 rainfall clusters corresponding to light (h=1), moderate (h=2), and heavy (h=3) rainfall

π_h: Cluster weight
μ_h: Cluster mean
Φ_h: Cluster precision (variance^{-1})



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Bayesian Inference

- Prior Distribution (Expert knowledge but weakly informative)

$$p_h \sim Dirichlet(a_1, a_2, a_3) \quad a_1 = 0.5; a_2 = 0.35; a_3 = 0.15$$

$$(m_h, f_h) \sim Normal(m_h | m_{0h}, kt_h) Gamma(t_h | a_{th}, b_{th})$$

$$m_{0h} = (1.0, 8.0, 20.0)$$ AMS definition of rainfall types

$$k = (1,1,1); a_{th} = (1.0, 1.0, 0.4); b_{th} = (1.0, 1.0, 1.0)$$ Weakly informative

- Full Conditional Posteriors

$$(m_h, f_h | -) \sim N(m_h | \hat{m}_h, \hat{k} f_h) Ga(f_h | \hat{a}_{th}, \hat{b}_{th})$$

$$\hat{k} = (k^{-1} + n_h)^{-1}; \hat{m}_h = \hat{k}(k^{-1} m_0 + n_h \bar{y}_h); \hat{a}_{th} = a_{th} + n_h/2$$

$$\hat{b}_{th} = b_t + \frac{1}{2}\left\{ \sum_{i=1}^{n_h} (y_i - \bar{y}_h)^2 + \left(\frac{n_h}{1 + k n_h} \right) (\bar{y}_h - m_0)^2 \right\}$$

$$(p_1, p_2, p_3 | -) \sim Dirichlet(a_1 + n_1, a_2 + n_2, a_3 + n_3)$$

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Gibbs Sampler

- Markov Chain Monte Carlo (MCMC)
  - Update cluster members from likelihood model
  - Update $\left(m_h, f_h \mid -\right) \sim N\left(m_h \mid \hat{m}_h, kf_h\right) Ga\left(f_h \mid \hat{a}_{th}, \hat{b}_{th}\right)$
  - Update $\left(p_1, p_2, p_3 \mid -\right) \sim Dirichlet\left(a_1 + n_1, a_2 + n_2, a_3 + n_3\right)$
- Constraints on μ_h ($\mu_1 < \mu_2 < \mu_3$) to deal with label switching problems
- Run 1000-iteration MCMC, the 1st 200 burn-in samples are discarded

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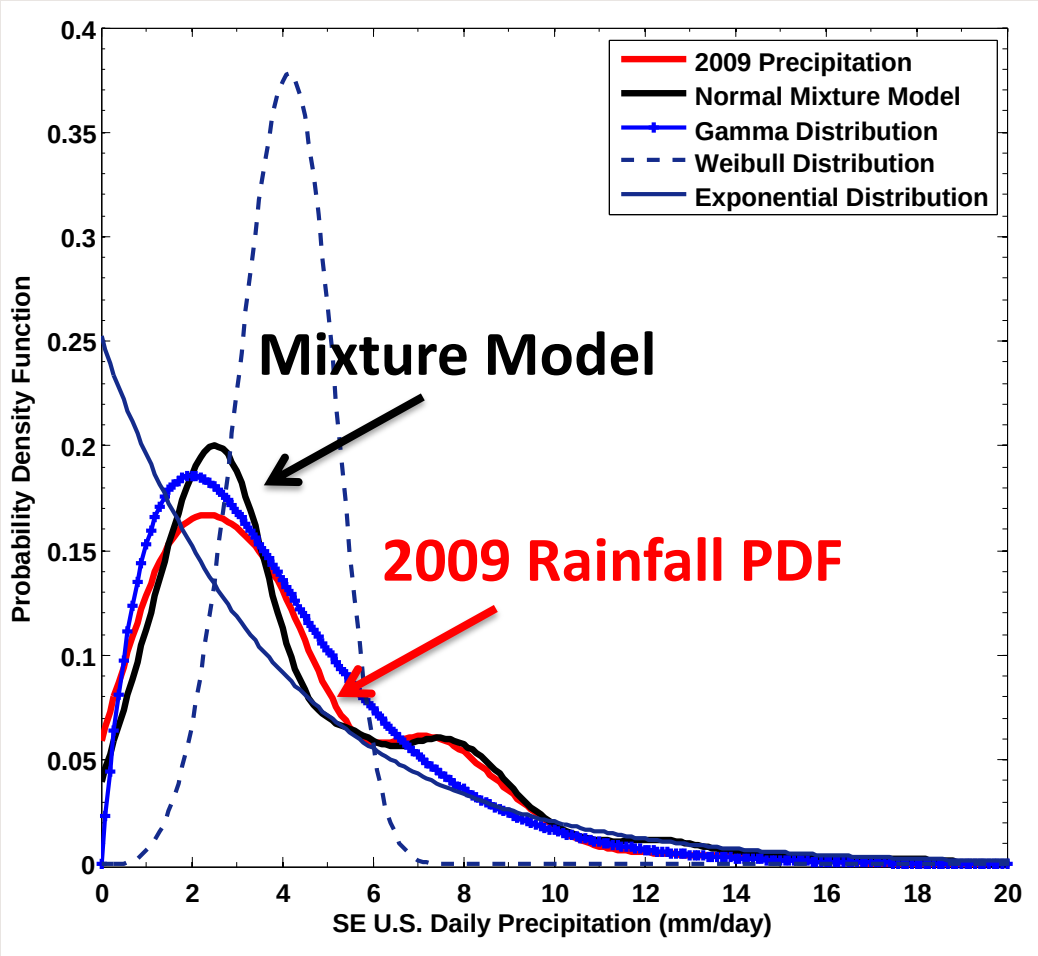
Model Performance: 2009 case



3-cluster *Normal* Mixture model outperforms traditional distribution models in describing the probability behavior of SE US summer rainfall

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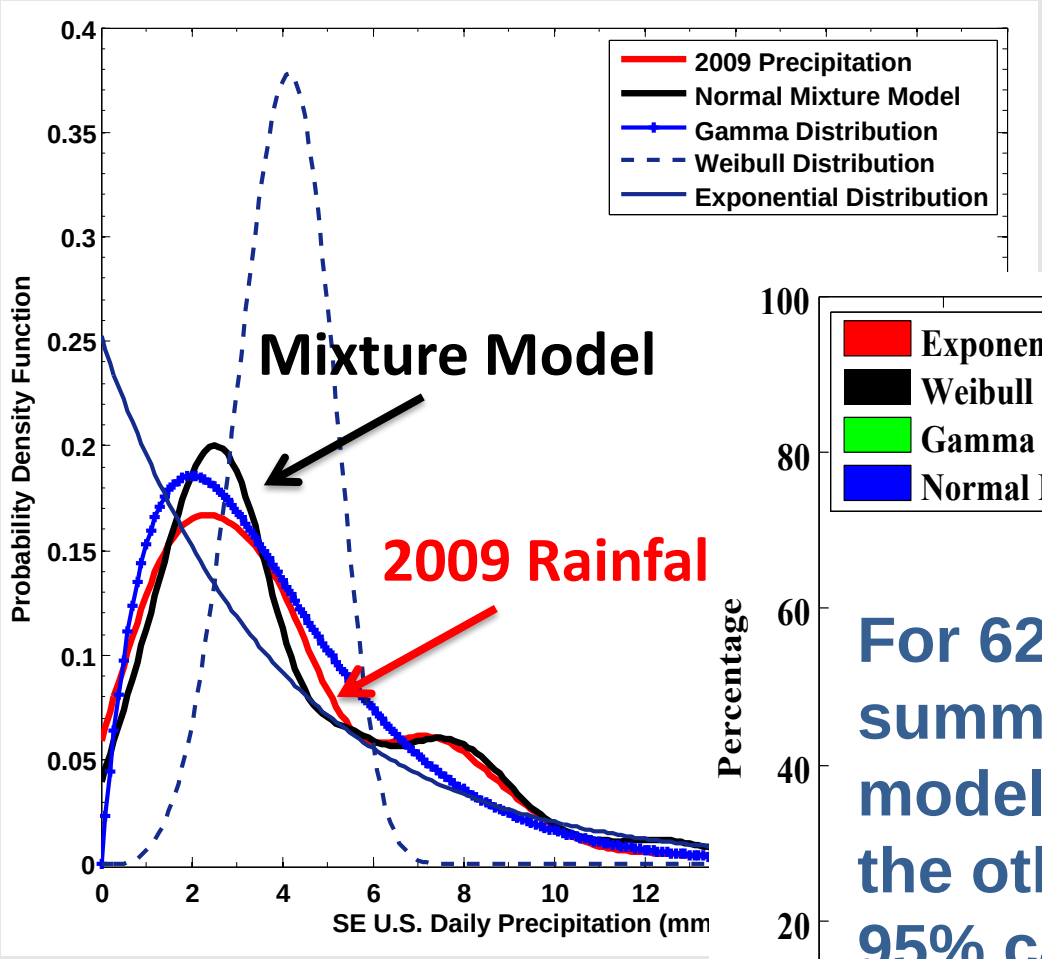
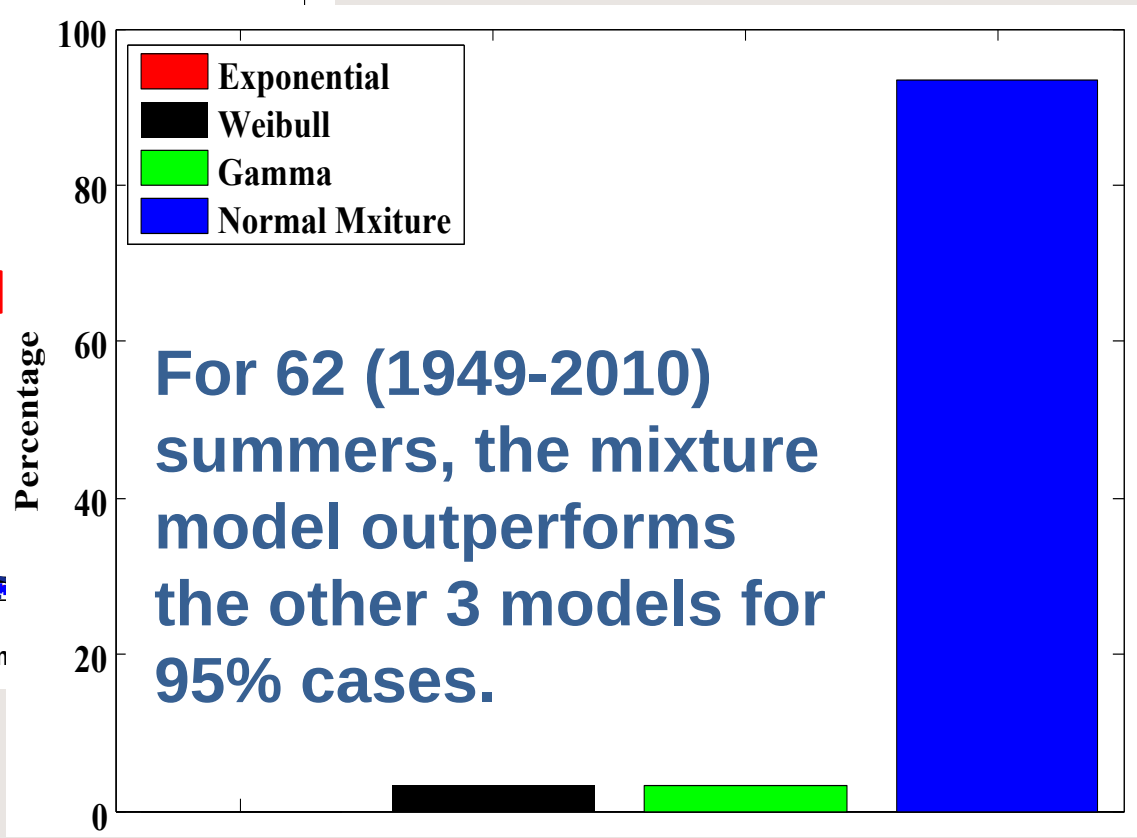
Model Performance: Goodness of Fit



3-cluster *Normal* Mixture model outperforms traditional



For 62 (1949-2010) summers, the mixture model outperforms the other 3 models for 95% cases.

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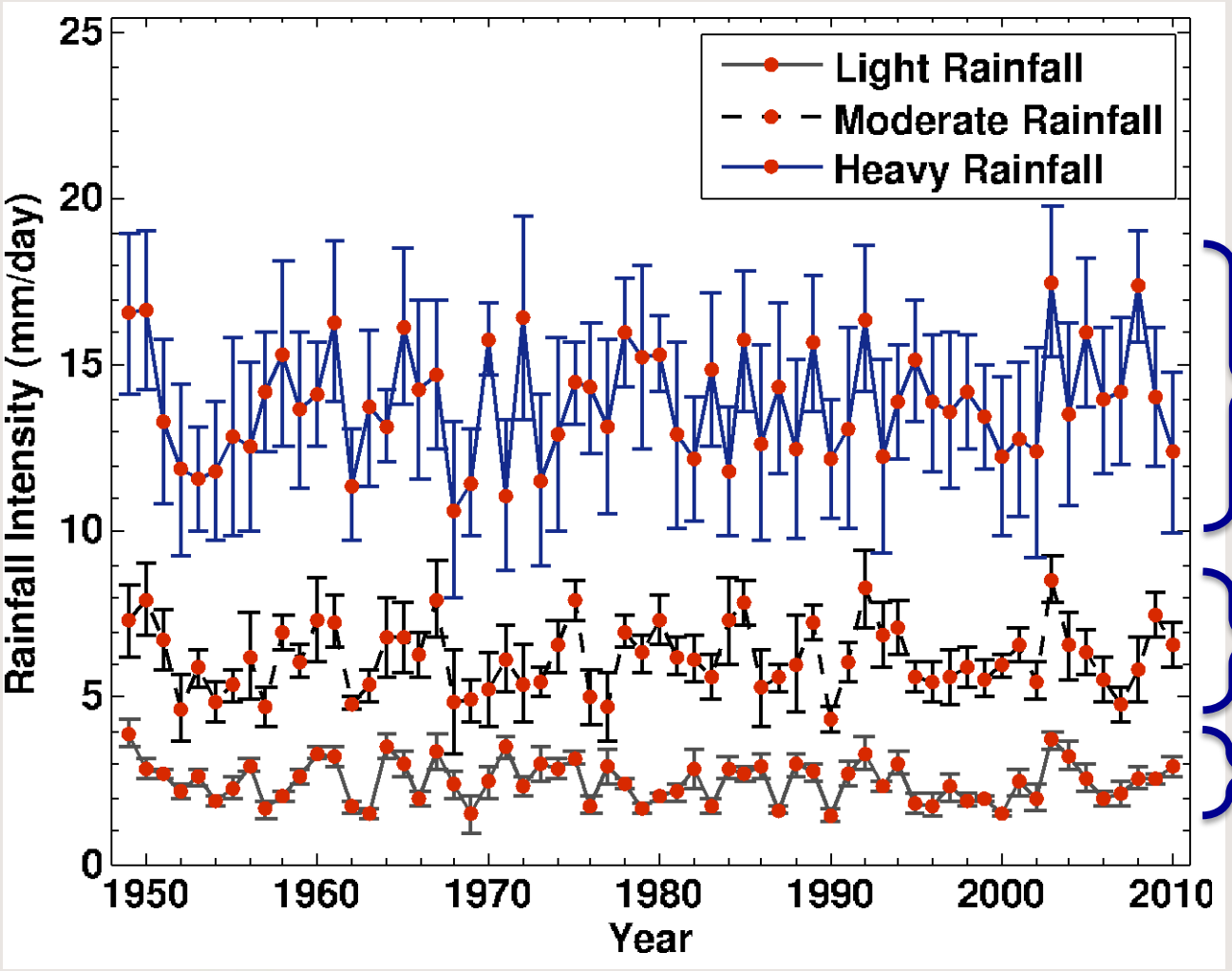
Bayesian Inference on μ_h



Heavy Rainfall (highest uncertainty)

Moderate Rainfall

Light Rainfall (lowest uncertainty)

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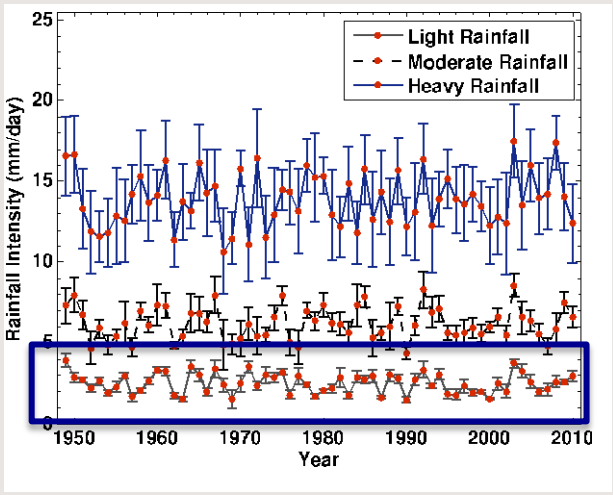
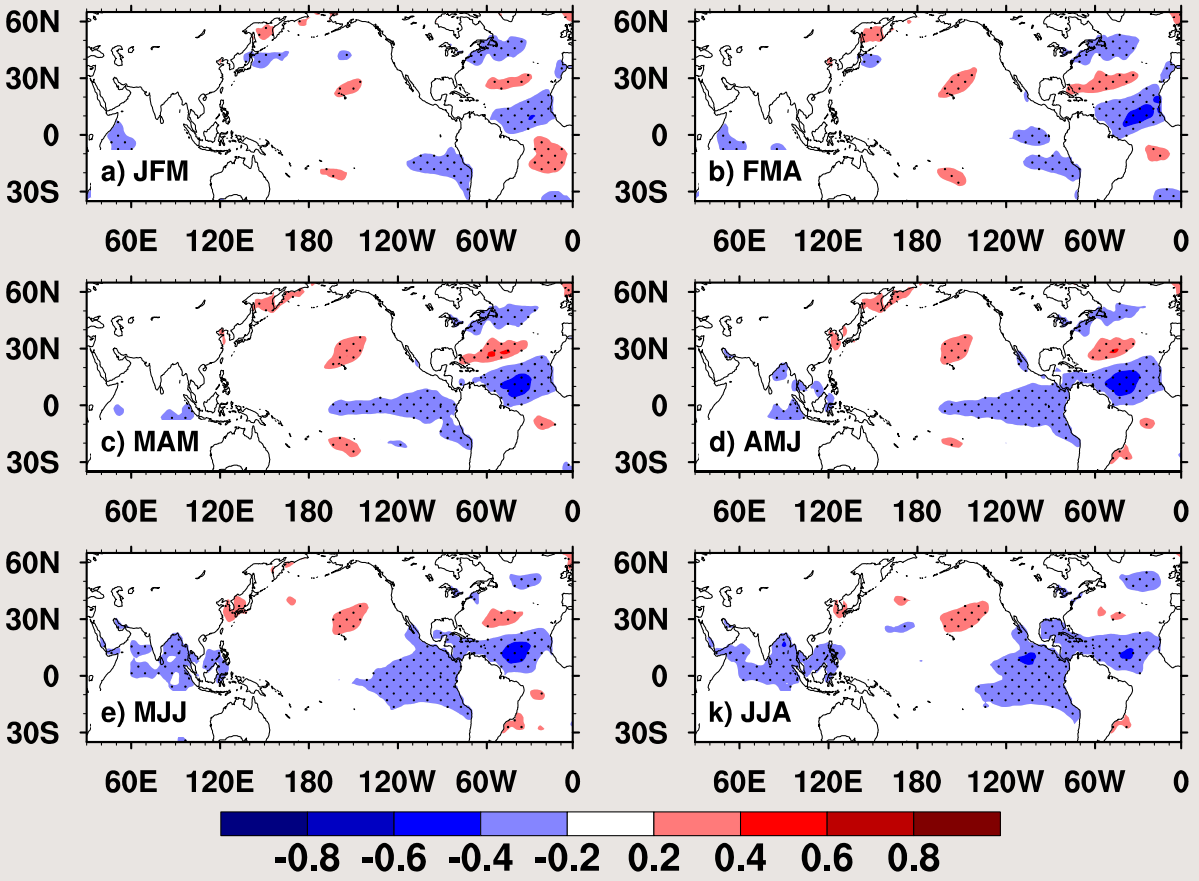
Light Rainfall & SSTA



La Niña and tripole SSTA over the North Atlantic occur 3 months ahead of the SE US light rainfall



Global SSTA (shaded; unit: normalized; dimensionless) regressed upon light rainfall intensity. SSTA significant at 0.05 level by 1000-time Monte-Carlo simulation is stippled.

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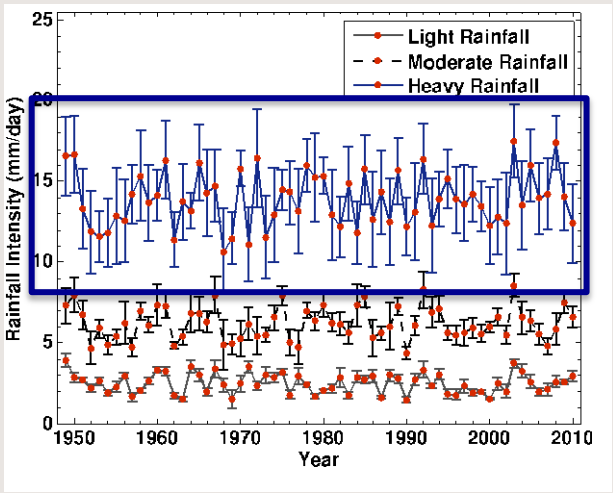
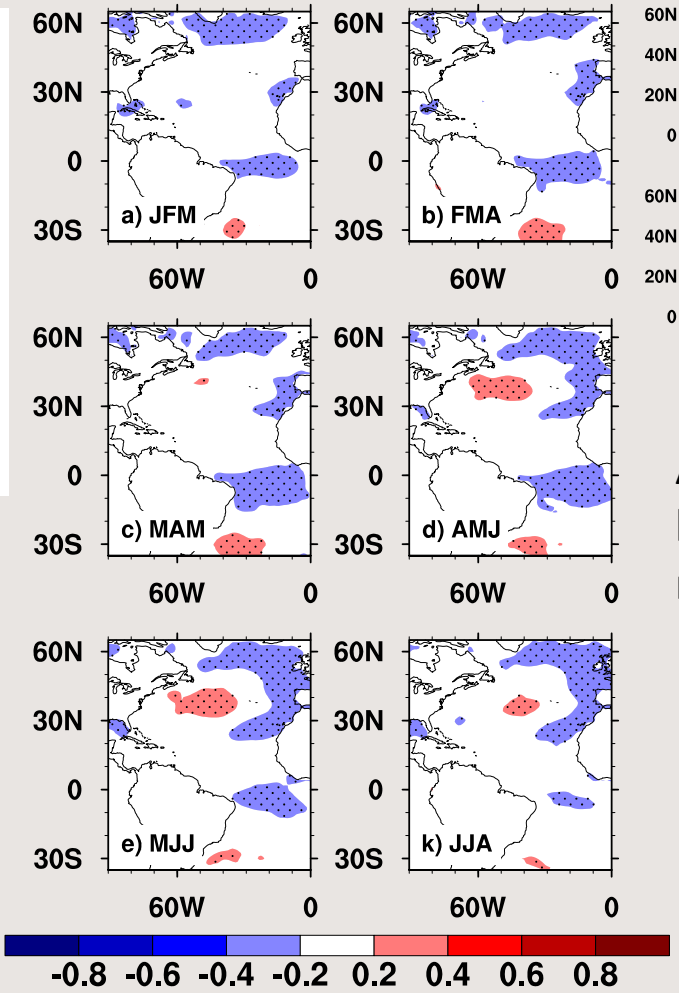
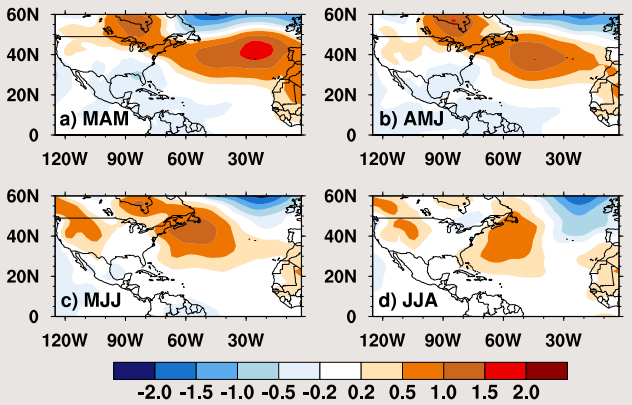
Heavy Rainfall & SSTA



SE US Heavy rainfall is associated with a "horseshoe-like" SSTA over the North Atlantic.





Atlantic SLP (shaded; unit: hPa) composite upon heavy rainfall intensity.

Atlantic SSTA (shaded; unit: normalized; dimensionless) regressed upon heavy rainfall intensity. SSTA significant at 0.05 level by 1000-time Monte-Carlo simulation is stippled.

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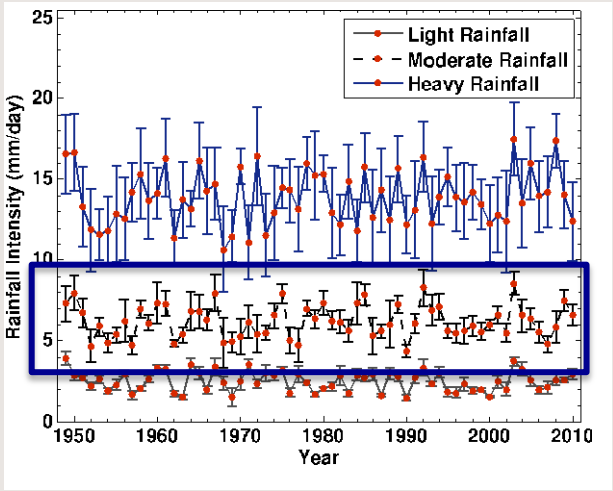
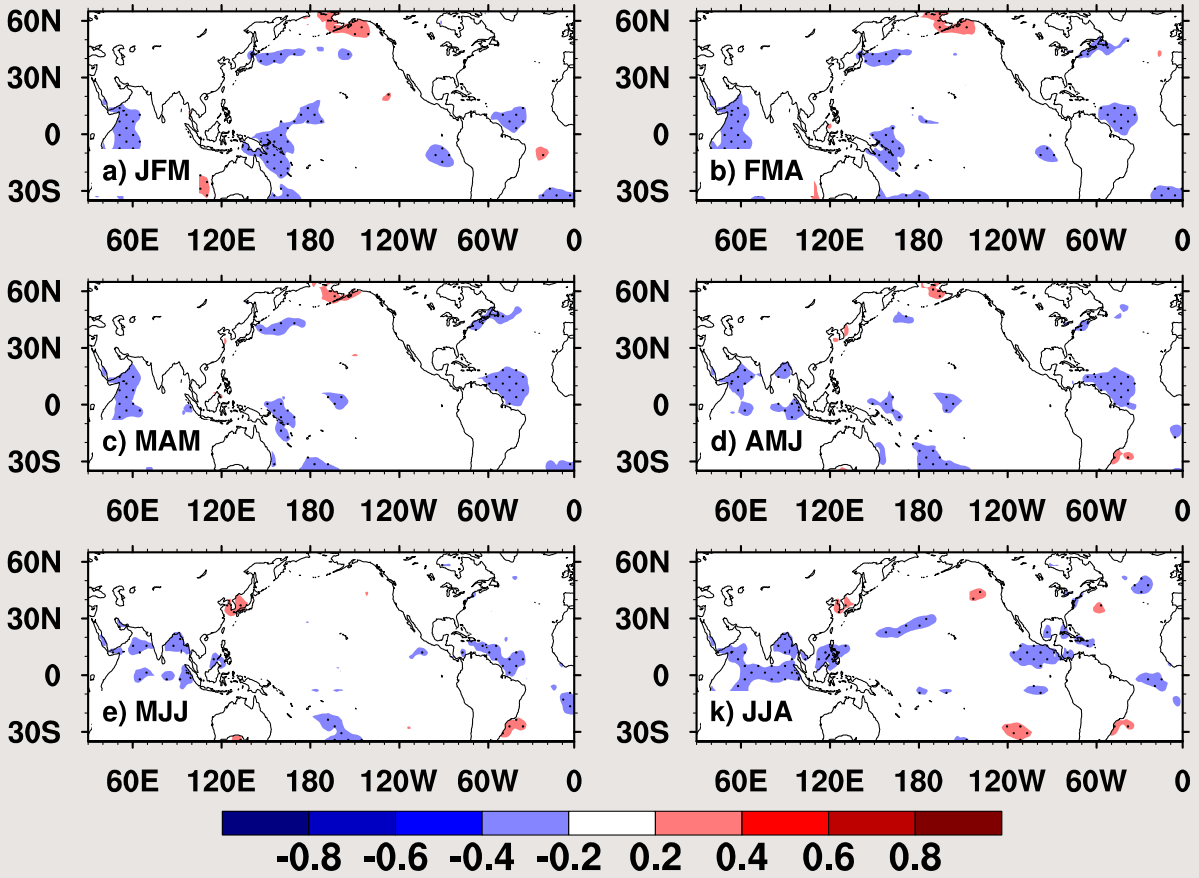
Moderate Rainfall & SSTA



No systematic SSTA pattern concurs with moderate rainfall



Global SSTA (shaded; unit: normalized; dimensionless) regressed upon moderate rainfall intensity. SSTA significant at 0.05 level by 1000-time Monte-Carlo simulation is stippled.

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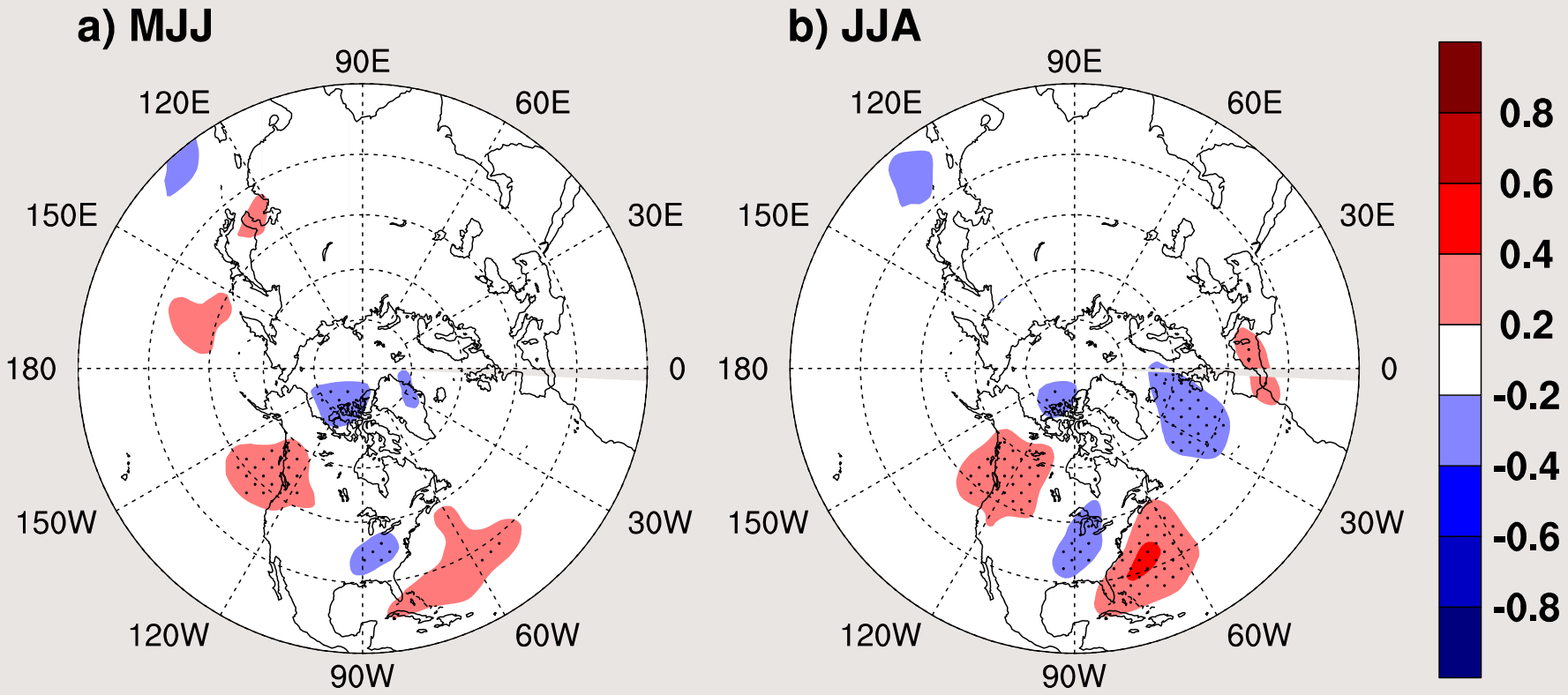
Moderate Rainfall & Atmo. Circulation

Moderate rainfall is likely generated due to atmospheric internal variability



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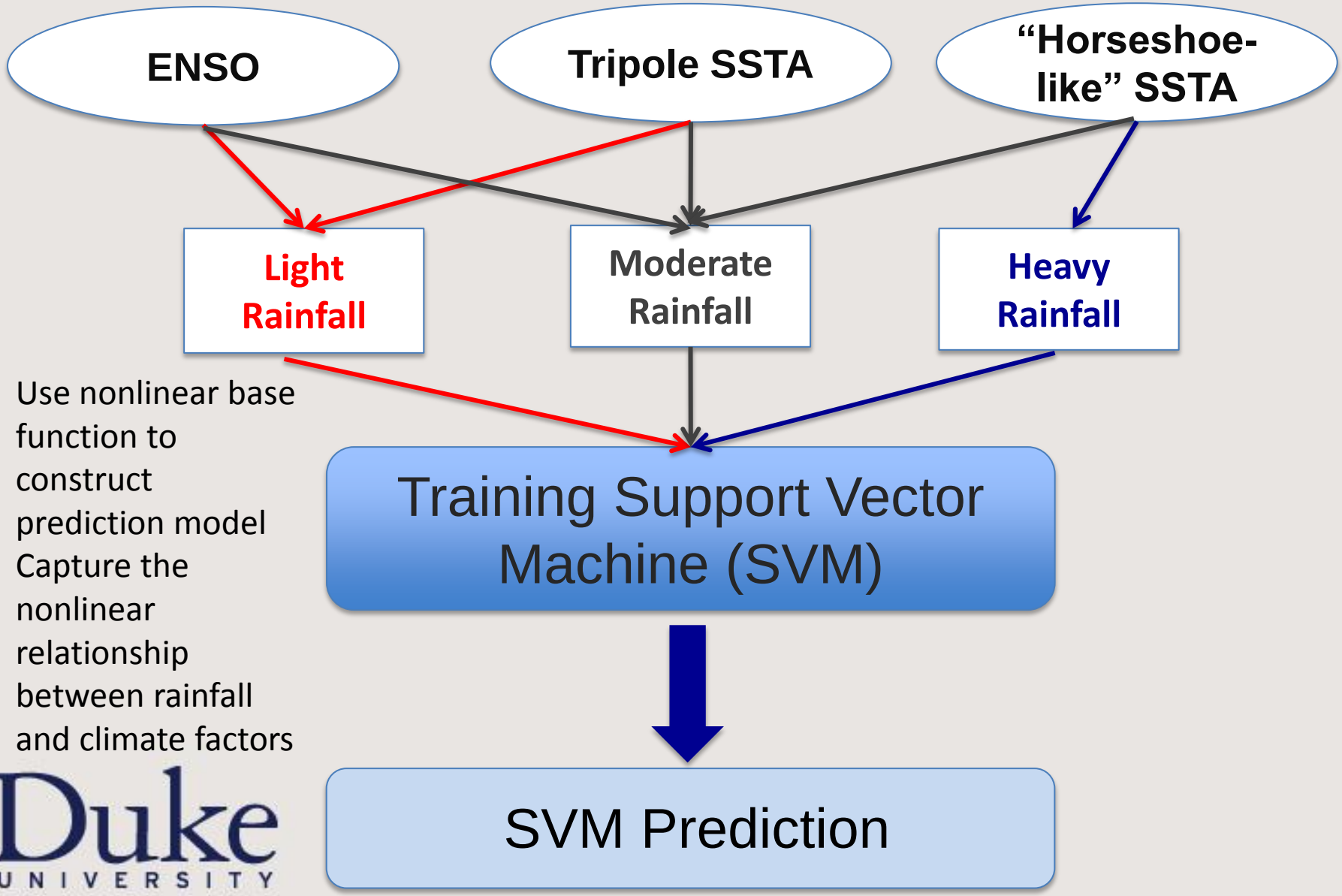
a) MJJ and b) JJA 850hPa geopotential height anomaly (shaded; Units: normalized, dimensionless) regressed upon SE US moderate rainfall intensity. Geopotential height anomalies significant at level by 1000-time Monte-Carlo simulation are stippled (From Li and Li, 2013: *Environ. Res. Letts.* In Press)

Prediction Model: SVM machine learning



- Use nonlinear base function to construct prediction model
- Capture the nonlinear relationship between rainfall and climate factors

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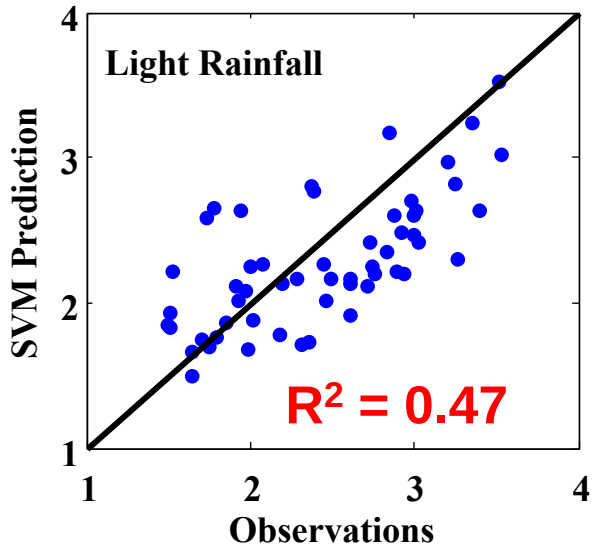
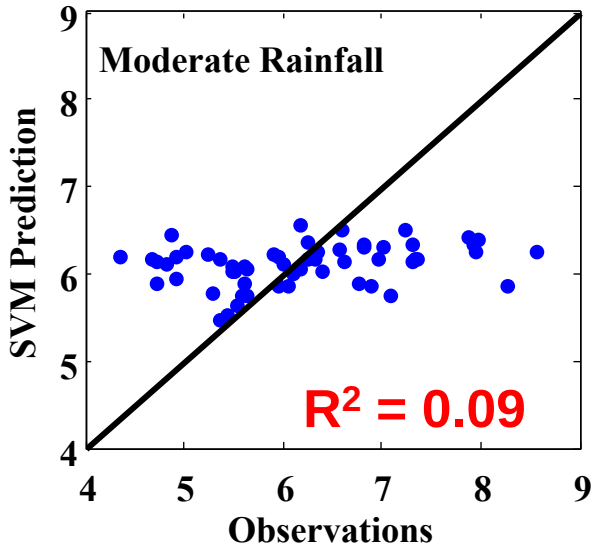
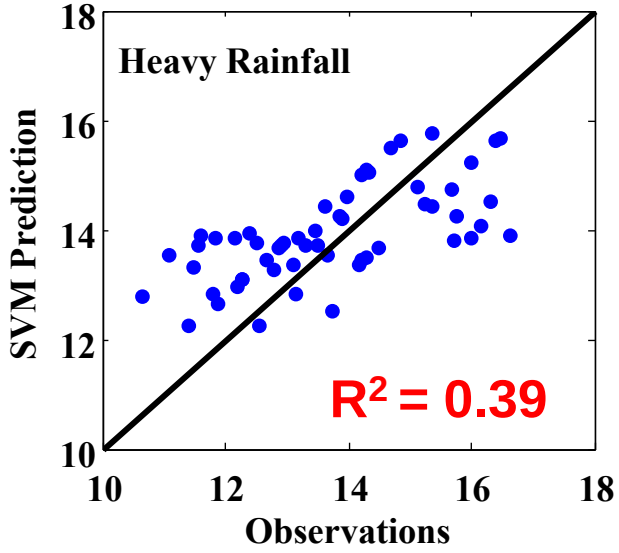
SE US Summer Rainfall Predictability

SVM **generate prediction skills** for *light Rainfall* and *heavy rainfall* given preceding SSTA

SVM **has no prediction skill** for *moderate rainfall*, most likely because moderate rainfall is generated due to atmospheric internal variability







	Predictors
Light Rainfall	ENSO, Tripole SSTA (3-month lead)
Moderate Rainfall	ENSO, Tripole SSTA, Horseshoe SSTA
Heavy Rainfall	Horseshoe SSTA (2-month lead)

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Concluding Remarks

- New rainfall framework based on a 3-cluster finite *Normal* mixture model better captures the probability distribution of light, moderate, and heavy rainfall over the SE US
- 3 rainfall clusters are linked to different climate factors:
  - 1) light rainfall ←ENSO+ North Atlantic Tripole SSTA;
    heavy rainfall ← Atlantic horseshoe-like SSTA
  - 2) moderate rainfall might be generated by atmospheric internal variability.
- Given the above SSTA-rainfall relationship, the support vector machine generate prediction skills in light and heavy rainfall, but no skills for moderate rainfall.

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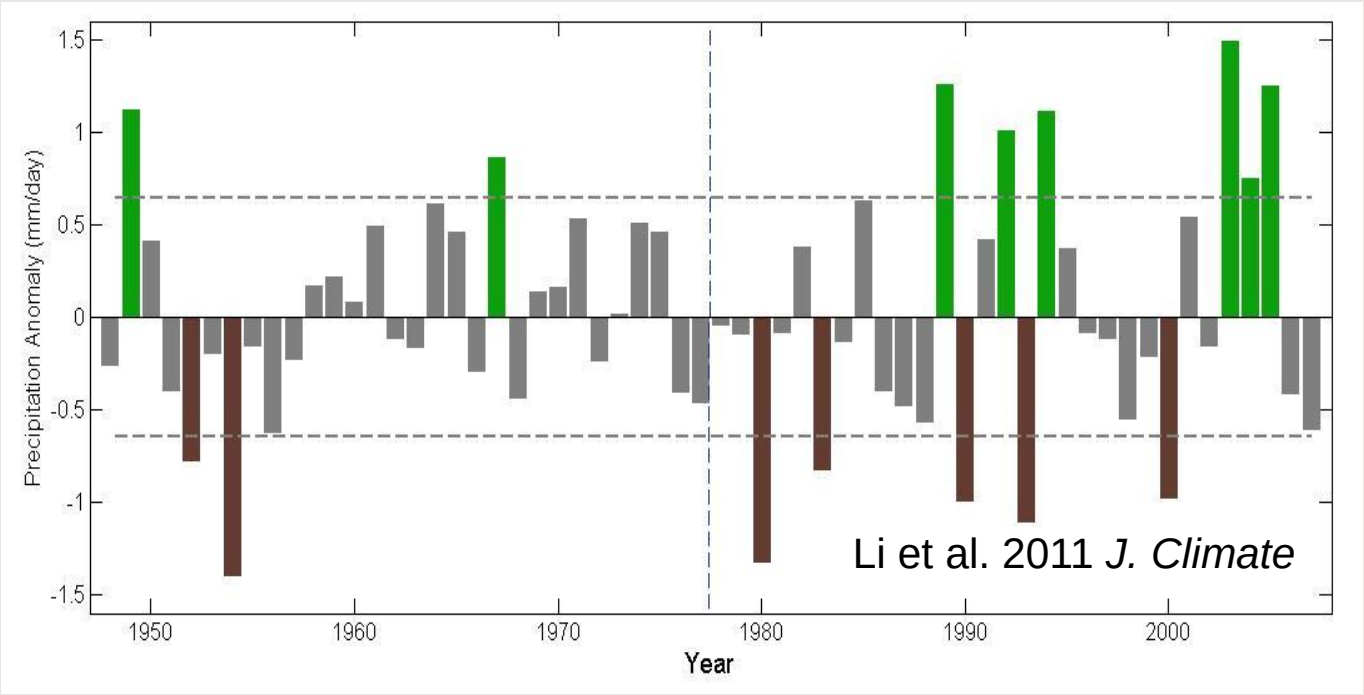
Thank You!



Q&A

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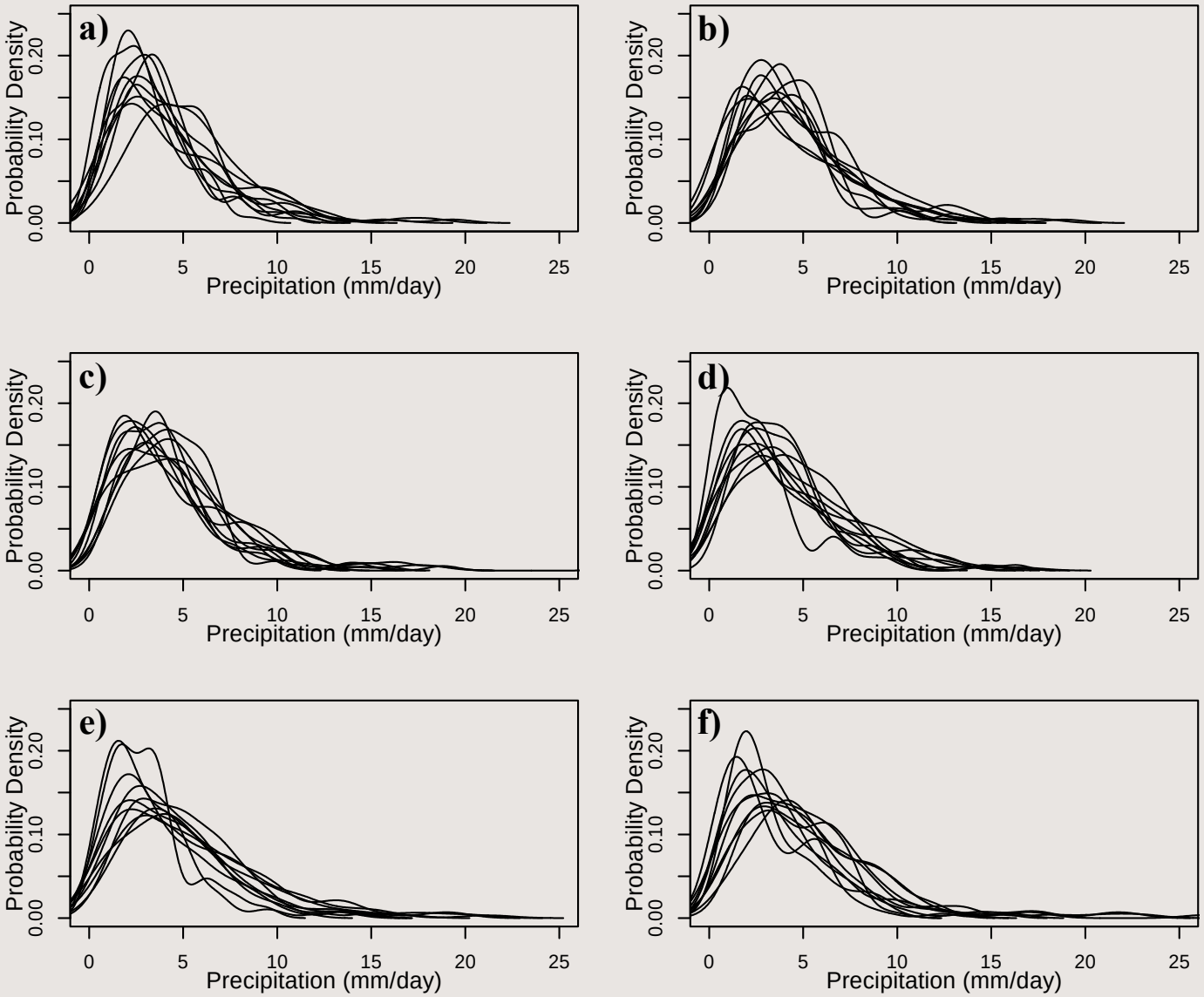
Rainfall PDFs



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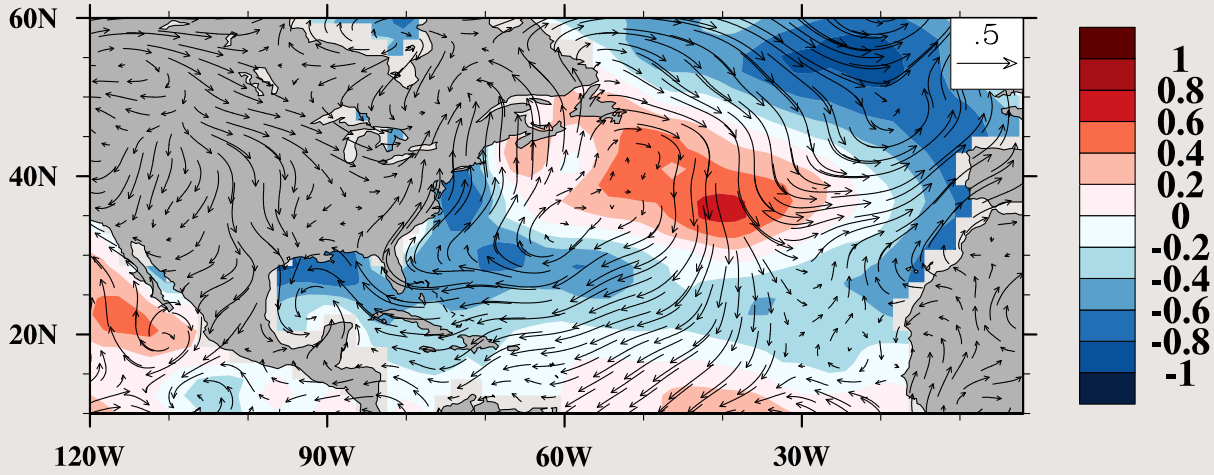
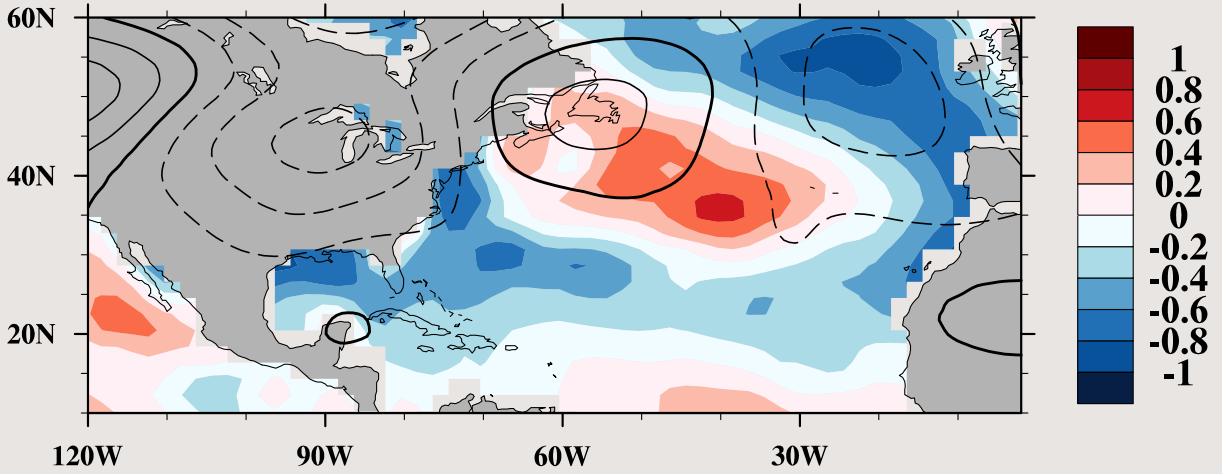
Horseshoe SSTA and Heavy Rainfall



SSTA and 1000hPa wind composite upon heavy rainfall intensity



SSTA and 200hPa geopotential height composite upon heavy rainfall intensity

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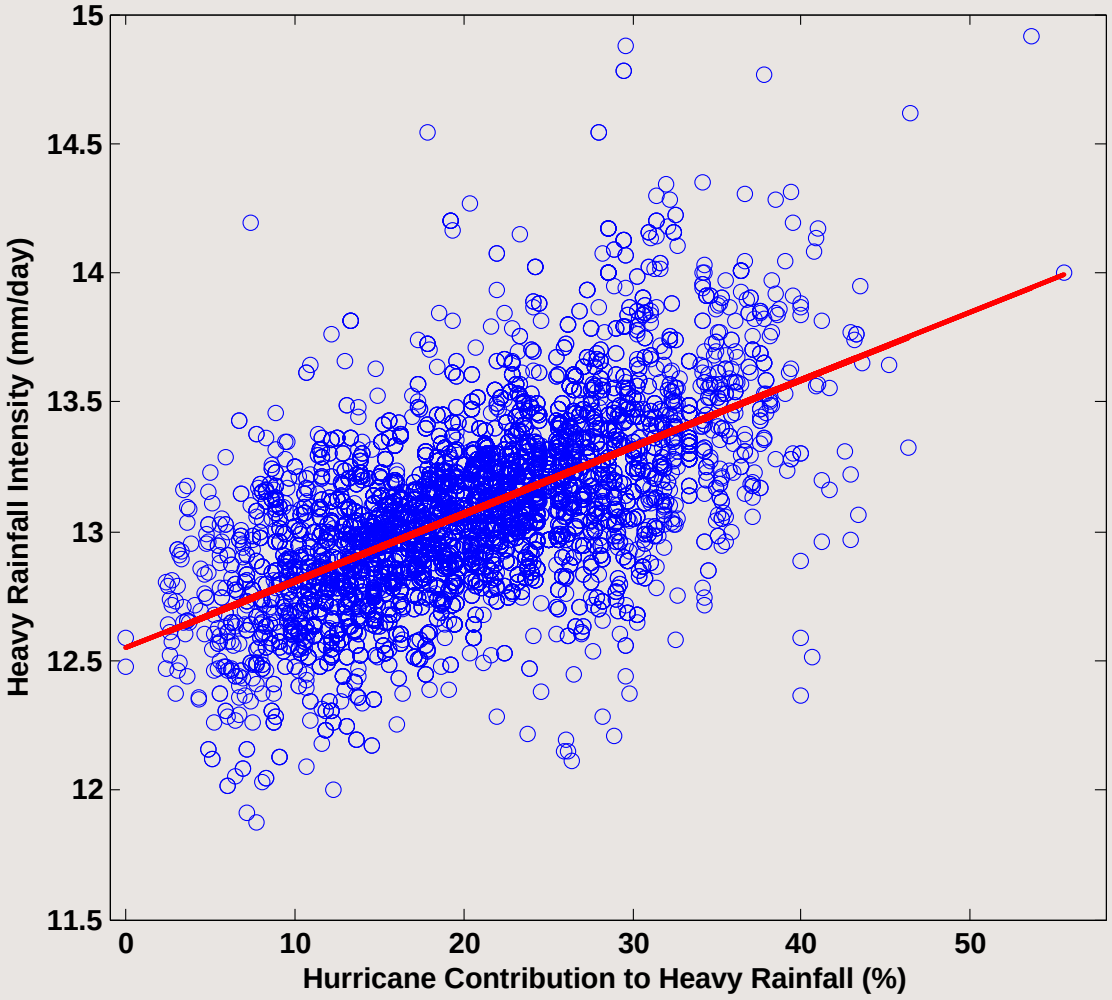
Hurricane Contribution to Heavy Rainfall



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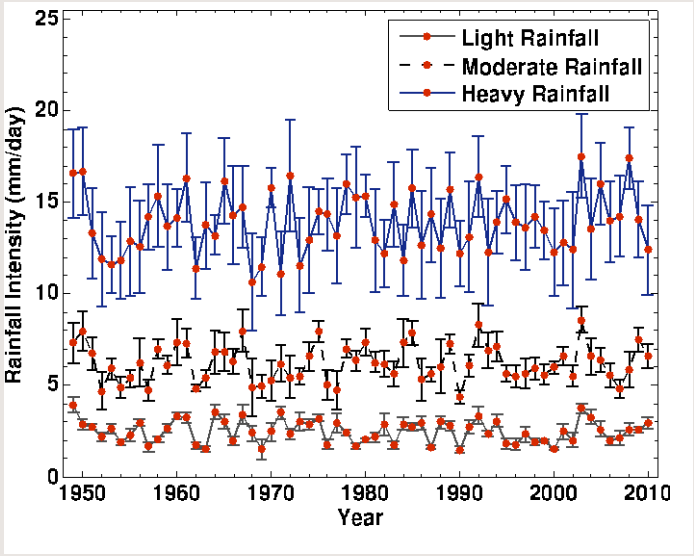
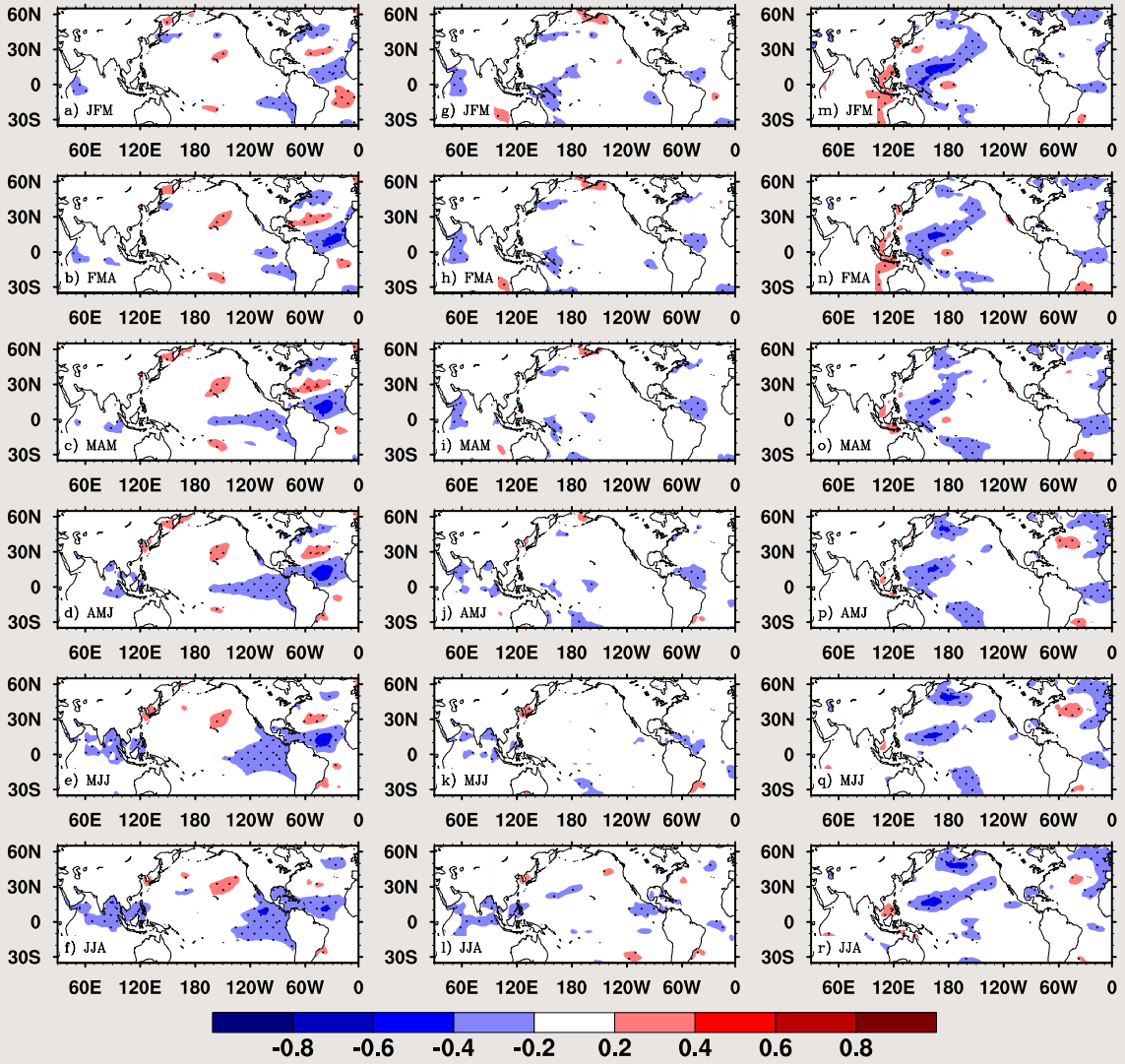
Rainfall & SSTA





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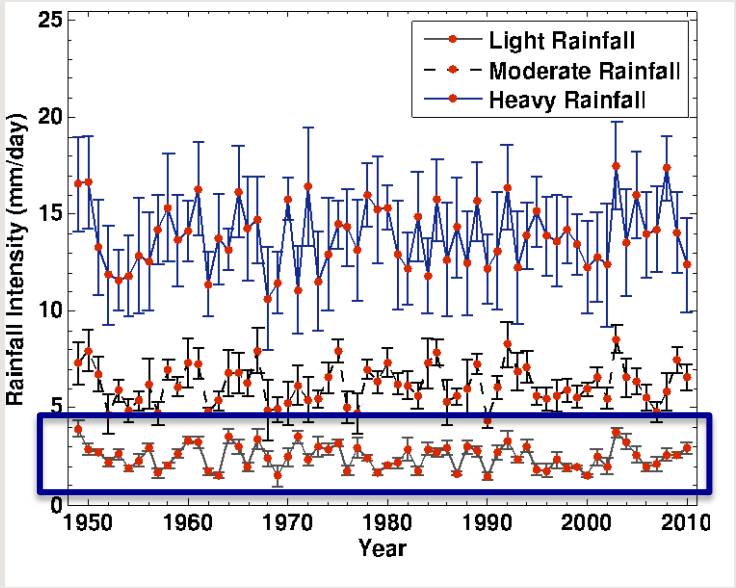
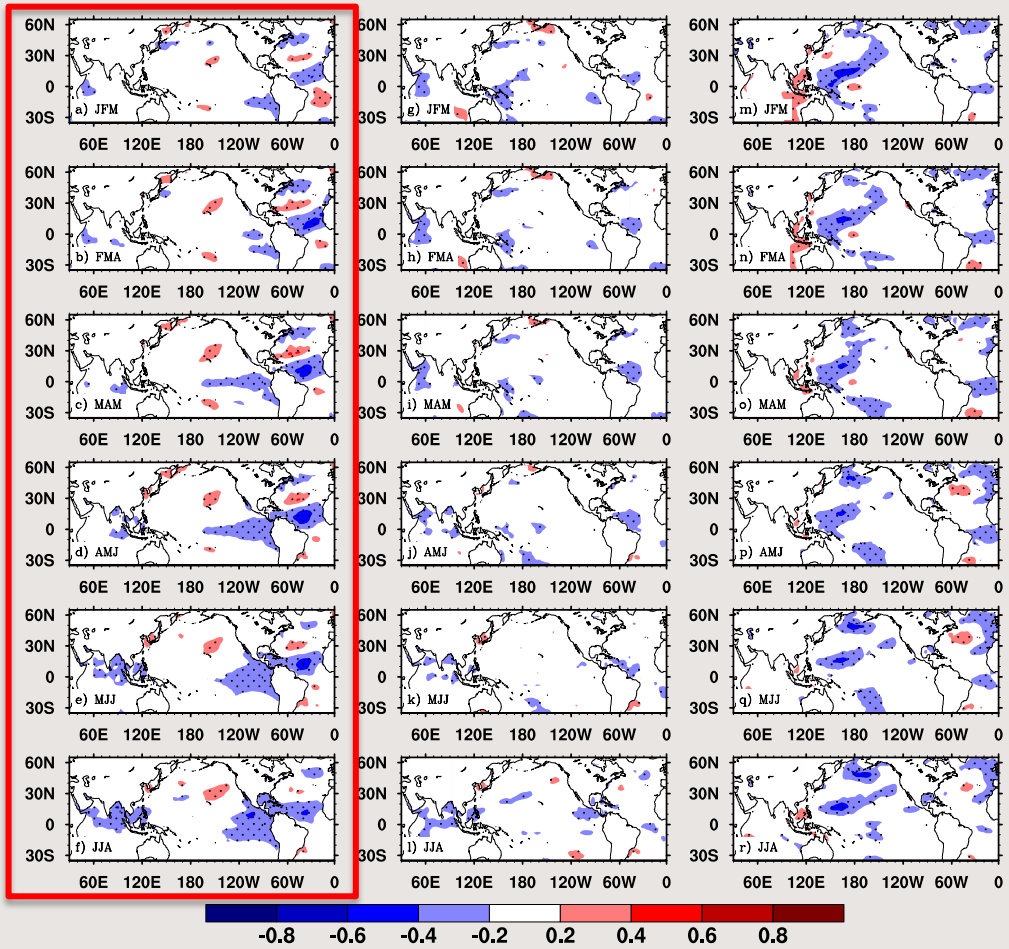
Light Rainfall & SSTA





La Nina and tripole SSTA over the North Atlantic occurs 4 months ahead of the SE US light rainfall

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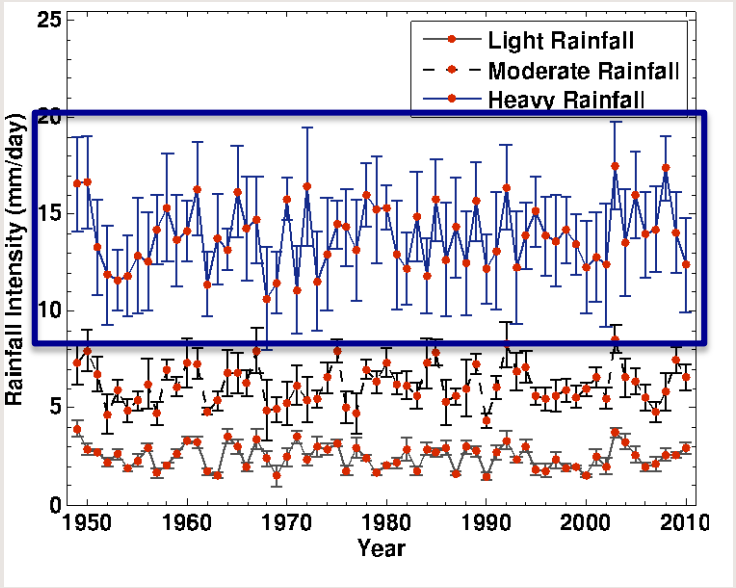
Heavy Rainfall & SSTA



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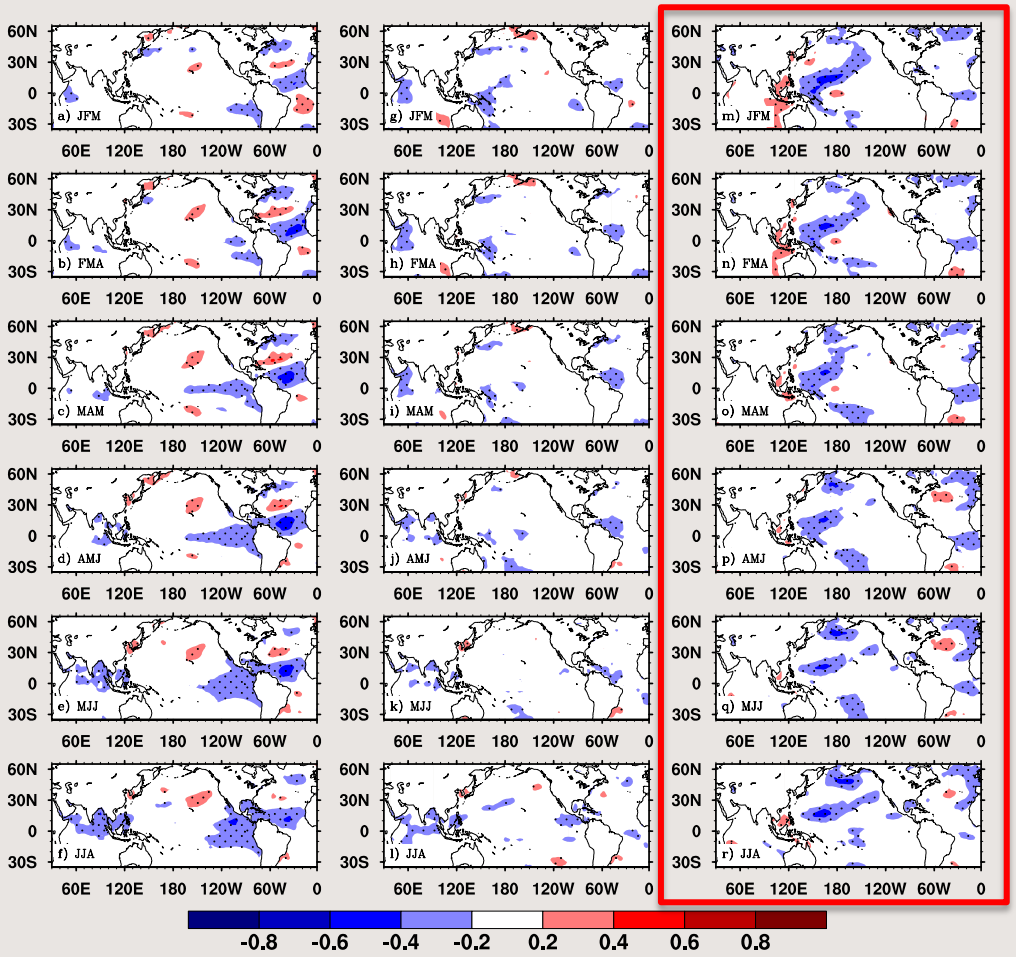

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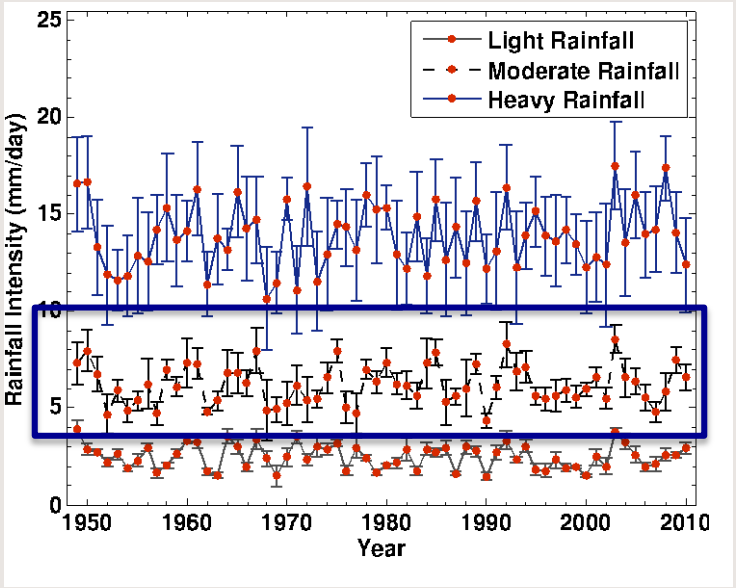
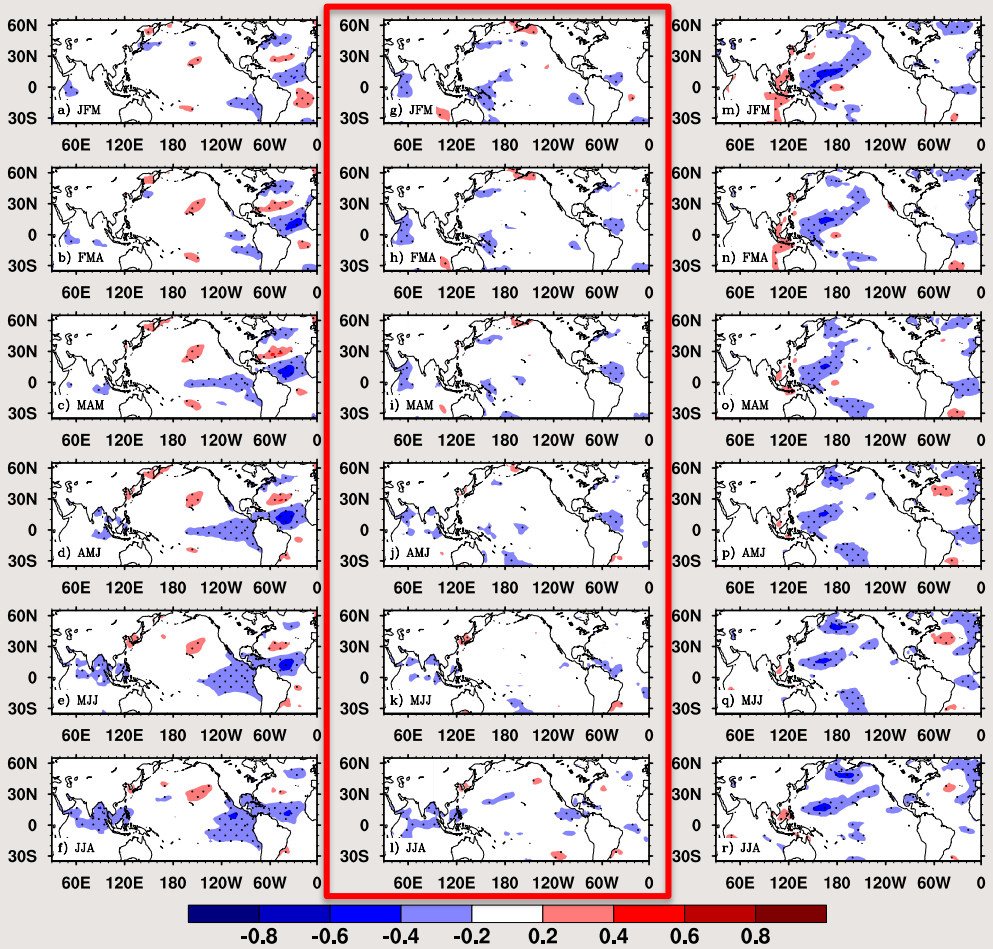
Moderate Rainfall & SSTA





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